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NASA CR-161291

STANDARD TRANSISTOR ARRAY (STAR)
Addendum 1 to Volume 1: CAPSTAR User's Guide

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July 26, 1979

Final Report

19 MAY 1983

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Prepared for

NASA - George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

482-13778

1 REPORT NO. NASA CR-161291	2. GOVERNMENT ACCESSION NO.	3 RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Standard Transistor Array (STAR) - Addendum 1 to Volume 1: CAPSTAR User's Guide		5 REPORT DATE July 26, 1979	
		6 PERFORMING ORGANIZATION CODE	
7 AUTHOR(S) G. W. Cox and B. D. Carroll		8 PERFORMING ORGANIZATION REPORT #	
9 PERFORMING ORGANIZATION NAME AND ADDRESS Electrical Engineering Department Auburn University Auburn, Alabama 36830		10. WORK UNIT NO.	
		11 CONTRACT OR GRANT NO. NAS8-31572	
12 SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		13. TYPE OF REPORT & PERIOD COVERED Contractor Report Final	
		14 SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This work was done under the technical supervision of Mr. Jack Matheney, George C. Marshall Space Flight Center, Alabama.			
16. ABSTRACT The cell placement techniques developed for use with the Standard Transistor Array (STAR) have been incorporated in a placement program, the Cell Arrangement Program for STAR (CAPSTAR). Instructions for use of this program are given in this document. Placement techniques are described in NASA CR-161289.			
17. KEY WORDS Placement techniques Standard Transistor Array (STAR) Custom logic design		18. DISTRIBUTION STATEMENT For Early Domestic Dissemination <i>82 Smith 7-19-79</i> F. BROOKS MOORE, Director, Electronics and Control Laboratory	
19. SECURITY CLASSIF. (of this report) Unclassified	20 SECURITY CLASSIF. (of this page) Unclassified	21 NO. OF PAGES 26	22 PRICE NTIS

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This document contains user information for CAPSTAR (Cell Arrangement Program for STAR) as implemented on the XDS SIGMA/5. A general description of the program is given first. Input data formats and output information are then discussed. Instructions for program execution are shown at the end of this guide.

Program Description

CAPSTAR is designed to provide two-dimensional placements of digital logic circuits on the Standard Transistor Array (STAR). The placements generated are near-optimum with respect to horizontal and vertical channel usage and the number of nets which can be routed in a linear fashion.

Input to the program consists of a description of circuit cells and interconnections. The circuit description is used to form a near-optimum one-dimensional placement of the cells. The one-dimensional placement is then 'folded' onto the STAR to form a two-dimensional layout. By use of various folding strategies, a number of different layouts are formed. The best few of these are selected and are improved by use of a simple interchange technique. Pads are placed in the best improved layout which is the program result.

CAPSTAR results are given in an output file which is in a format suitable for use by other programs (such as a STAR router). For user convenience, intermediate and final results are also given in a hard-copy form.

Due to the limited storage available, certain limits are imposed on the characteristics of input circuits. No more than 999 cells, 500 nets, and 98 pads are allowed. The STAR selected for use cannot exceed 30 cell rows by 100 columns. In addition, while no restrictions are made on the numbers assigned to circuit nets, cell numbers greater than 999 are not allowed.

Input Data Format

The circuit description and CAPSTAR control data should be provided in an input file available for program access. The input file consists of a series of 80-character records. Only the first 72 characters of each record are significant and positions 73-80 can be used for record numbering or other user information.

Each record in the input file consists of format-free numeric or character items. The end of a numeric item is sensed whenever a blank, comma, or the end of the record is seen. The end of a character item is indicated by a comma or record end. A record can be continued by leaving the first

four positions of the succeeding record blank. A record may be continued any number of times.

The input file may consist of CAPSTAR control records, circuit definition records, and passed records. The control records either specify settings for CAPSTAR variables or act as headers for groups of circuit definition records. The passed records are those which are not recognized as control or definition records and are included in the CAPSTAR output file for use by later programs.

Control Records

Each control record consists of a single CAPSTAR control statement beginning in column 1. Data pertaining to the statement appears either in the same record or in following records. A list of CAPSTAR control statements, their function, and necessary data is shown below. Where allowed, the shortened form of the control statement is shown in parentheses.

C

Function- Denotes a comment to be shown in the narrative output.

Data - Comment in columns 5-72 of the record (no continuation allowed).

Passed - No

DEBUG (DEBU)

Function- Turns on CAPSTAR debugging output.

Data - None.

Passed - No

FIND,

Function- Sets the upper limit on number of folding solutions to be found (initially 50). Specifying 0 causes all possible folding solutions to be generated.

Data - Upper limit following comma.

Passed - No

GATES TO PATTERNS (GATE)

Function- Header for cell type list.

Data - Cell type list in following records.

Passed - Yes

IMPROVE, (IMPR,)

Function- Specifies number of folding solutions to be improved (initially 3, max=10).

Data - Number of solutions following comma.

Passed - No

LINEAR ORDER (LINE)

Function- Header for user-entered linear order. Causes disabling of CAPSTAR clustering and linear ordering steps.

Data - Linear order in following records.

Passed - No

NAME,

Function- Specifies circuit title for output listing.

Data - Circuit title (8 characters) after comma.

Passed - Yes

NEIGHBORHOOD, (NEIG,)

Function- Specifies row and cell neighborhood sizes for placement improvement step (initially 1,1).

Data - Row, cell neighborhood sizes following comma.

Passed - No

NETS

Function- Header for circuit net lists.

Data - Net lists in following records.

Passed - Yes

STAR SIZE, (STAR,)

Function- Specifies STAR dimensions.

Data - STAR size (cell rows, transistor columns)
following comma.

Passed - Yes

STEP,

Function- Specifies CAPSTAR steps to be performed
(initially all).

Data - Step names (CLUSTER, LINEUP, WIRECROSS, FOLD)
separated by commas following 'STEP,'.

Passed - No

Circuit Definition Records

The cell type list, net list, and user-defined linear order are entered as a series of numeric records following the appropriate header record. The end of a list is assumed when a non-numeric item or the end of the input file is seen. The format of each of the three lists is shown below.

Cell Type List (Following 'GATES TO PATTERNS')

In this list, each of the circuit cells and pads is associated with a STAR standard cell or pad type number. The format of each record in this list is

cell1 type1 cell2 type2

For example, if cell number x is type $1000+x$, a typical cell type list record is

```
1 1001 2 1002 3 1003 4 1004 .
```

Sufficient records to specify each cell or pad in the circuit should be included.

The list is passed to the output file with certain adjustments. These adjustments involve re-assignment of pad type numbers based on the pad position in the final placement. In the input file, input pads are type 9200 and output pads are type 9210. For pads placed at the top or bottom of the STAR, the type numbers are unchanged. For input pads placed at the sides of the STAR, the type number is changed to 9100. For an output pad placed at the left, the type number is changed to 9110. For output pads placed at the right, the type number is changed to 9120.

Net List (Following 'NETS')

The connection points (cell number, pin number) of each net in the circuit are identified in this list. The format of each record is

```
net cell1 pin1 cell2 pin2 . . . .
```

For example, if net 5 is connected to pin 1 of cells 6, 7, and 8, the net list record for net 5 is

```
5 6 1 7 1 8 1 .
```

For large nets, more than one input file record may be required. Extension of the net may be accomplished either by use of the record continuation feature or by repetition of the net number at the beginning of the next record. Thus, either

```
5 6 1
  7 1 8 1
```

or

```
5 6 1
5 7 1 8 1
```

can be used to enter net 5, above. If the second of these net continuation forms is used, the continuation records must immediately follow the initial record for the net.

Information specified in the net list is passed to the output file after modification of all continuations to the second form, above.

Linear Order (Following 'LINEAR ORDER')

Each cell and pad in the network should be included in this list if the user-entered linear order option is selected. The list format is

```
cell1 cell2 cell3 cell4 . . . .
```

Record continuation is allowed, but not required in this list. The linear order is not passed to the output file.

Example Input File

Circuit 'EXAMPLE' has 4 nets: net 10 connects pin 4 of cells 1-4, net 20 connects pin 5 of cells 1-20, net 30 connects pin 1 of cells 2,3,99 and 101, and net 40 connects pin 1 of cells 4 and 102. Cells 1-19 are type 1640, cells 20 and 99 are type 1820, 101 is an input pad (type 9200), and pad 102 is output (type 9210). The STAR to be used consists of 8 rows and 24 columns. 50 folding solutions are to be formed and the best 5 improved. The row and cell neighborhood sizes are 1 and 3, respectively. The input file for this job is shown in Figure 1.

CAPSTAR Output

The output information provided by CAPSTAR consists of a file suitable for use by other programs and of user (narrative) output. These outputs are discussed in this section.

Narrative Output

CAPSTAR narrative output is provided in line-printer format on FORTRAN channel 6. Each CAPSTAR step is identified by a header line showing the step and circuit names. An explanation and example of the narrative output provided by each step is shown in the following paragraphs.

```

C
C      THIS IS AN EXAMPLE CAPSTAR APPLICATION
C
C      NAME, EXAMPLE
C
C      FIND, 50
C
C      IMPROVE, 5
C
C      NEIGHBORHOOD, 1,3
C
C      STAR SIZE, 8 24
C
C      GATES TO PATTERNS
1 1640 2 1640 3 1640 4 1640 5 1640 6 1640 7 1640 8 1640
9 1640 10 1640 11 1640 12 1640 13 1640 14 1640 15 1640
16 1640 17 1640 18 1640 19 1640 20 1820 99 1820
101 9200 102 9210
C
C      NETS
10 1 4 2 4 3 4 4 4
20 1 5 2 5 3 5 4 5 5 5 6 5 7 5 8 5
    9 5 10 5 11 5 12 5 13 5 14 5
20 15 5 16 5 17 5 18 5 19 5 20 5
30 2 1 3 1 99 1 101 1
40 4 1 102 1

```

Figure 1. Example Input File

Data Entry Step

Each control and passed record in the input file is echoed on the listing. The cell type definitions are displayed with cell width information as obtained from the STAR cell width library (STARWIDLIB). The cells composing each net in the circuit are also shown. At the end of the section, the result of a cross-check between the various lists is given.

The data entry step output for the cell type and net lists of the example application is shown in Figure 2.

Clustering Step

For each cell (cell number < 1000) or cluster (cell number > 1000) to be combined, the cell number, width and number of nets is shown. The statistics for each candidate for combination and the effect of combination on the total chip metal are calculated and displayed in tabular format. The combined cells and resultant cluster are then shown along with the cluster width and nets absorbed by combination. The information printed for a typical combination is shown in Figure 3.

Following clustering of all cells, a summary of cell combination is printed as shown in Figure 4.

GATES TO PATTERNS

CELL 1	TYPE 1640	WIDTH 6
CELL 2	TYPE 1640	WIDTH 6
CELL 3	TYPE 1640	WIDTH 6
CELL 4	TYPE 1640	WIDTH 6
CELL 5	TYPE 1640	WIDTH 6
CELL 6	TYPE 1640	WIDTH 6
CELL 7	TYPE 1640	WIDTH 6
CELL 8	TYPE 1640	WIDTH 6
CELL 9	TYPE 1640	WIDTH 6
CELL 10	TYPE 1640	WIDTH 6
CELL 11	TYPE 1640	WIDTH 6
CELL 12	TYPE 1640	WIDTH 6
CELL 13	TYPE 1640	WIDTH 6
CELL 14	TYPE 1640	WIDTH 6
CELL 15	TYPE 1640	WIDTH 6
CELL 16	TYPE 1640	WIDTH 6
CELL 18	TYPE 1640	WIDTH 6
CELL 19	TYPE 1640	WIDTH 6
CELL 20	TYPE 1820	WIDTH 14
CELL 99	TYPE 1820	WIDTH 14
PAD 101	TYPE 9200	
PAD 102	TYPE 9210	

C

NETS

NET 10	1	2	3	4					
NET 20	1	2	3	4	5	6	7	8	9
	10	11	12	13	14	15	16	17	18
	19	20							
NET 30	2	3	99	101					
NET 40	4	102							

END OF INPUT DATA

DATA CROSS-CHECK INITIATED

DATA CROSS-CHECK COMPLETED

Figure 2. Data Entry Step Output

CELL TO BE COMBINED = 1003 WIDTH = 12 NETS = 2

DELTA METAL	CAND.WIDTH	CAND.NETS	NETS IF COMB.	CANDIDATE
5.7395	12	4	4	1004
4.3046	12	3	3	1005
3.1311	14	1	2	20
2.8698	12	1	2	1007
2.8698	12	1	2	1008
2.8698	12	1	2	1009
2.8698	12	1	2	1010
2.8698	12	1	2	1011
3.6370	18	1	2	1012

CELL 1013 REPLACES 1003 & 1007 WIDTH = 24

Figure 3. Output Shown for Single Cluster Formation

CELL COMPOSED OF CELLS

1001-	101	2										
1002-	102	4										
1003-	1	5										
1004-	101	3	2									
1005-	102	6	4									
1006-	7	8										
1007-	9	10										
1008-	11	12										
1009-	13	14										
1010-	15	16										
1011-	17	18										
1012-	19	7	8									
1013-	1	9	5	10								
1014-	101	11	3	2	12							
1015-	102	13	6	4	14							
1016-	15	17	16	18								
1017-	20	19	7	8								
1018-	99	101	11	3	2	12						
1019-	1	15	9	5	17	16	10	18				
1020-	102	20	13	6	4	19	14	7	8			
1021-	99	1	101	15	9	5	11	3	2	17	16	
	10	12	18									
1022-	102	99	20	13	6	4	1	101	19	14	15	
	9	5	11	3	2	7	17	16	10	12	8.	
	18											

NORMAL CLUSTERING STEP TERMINATION

Figure 4. Clustering Step Summary Output

Linear Ordering Step

The generated linear cell order is shown in 15(I4) format. The output of this step for the example application is shown in Figure 5.

Wirecross Step

The linear order is displayed vertically with both forward (FWID) and reverse (RWID) cumulative cell widths shown. Each circuit net is shown to the right of the linear order with connections to a cell indicated by "-".

The wirecross output for the example circuit is shown in Figure 6.

Placement Step

At the beginning of the placement step, CAPSTAR forms the requested number of folding solutions. The highest rated IMPROVE of these are selected and ratings are shown. Start and end of placement improvement are noted and the rating data for the highest rated improved placement is shown. The format of this output is shown in Figure 7.

In this output, "QUALITY" is the estimated fraction of all layouts of the circuit with ratings lower than the placement of interest. Horizontal and vertical ratings reflect the predicted fraction of the available channel area which will be used in placement routing. Pads are not

LINEAR ORDER														
20	19	7	8	13	14	6	102	4	99	101	2	3	11	12
1	5	9	10	15	16	17	18							

Figure 5. Linear Ordering Step Output

FWID	RWID	CELL			
0	142				
14	128	20	-20		
20	122	19	-20		
26	116	7	-20		
32	110	8	-20		
38	104	13	-20		
44	98	14	-20		
50	92	6	-20		
50	92	102	20	-40	
56	86	4	-20	-40	-10
70	72	99	20	-30	10
70	72	101	20	-30	10
76	66	2	-20	-30	-10
82	60	3	-20	-30	-10
88	54	11	-20		10
94	48	12	-20		10
100	42	1	-20		-10
106	36	5	-20		
112	30	9	-20		
118	24	10	-20		
124	18	15	-20		
130	12	16	-20		
136	6	17	-20		
142	0	18	-20		

Figure 6. Wirecross Output

50 SOLUTIONS FOUND IN 59 TRIES

5 BEST SELECTED

NUMBER RATING*10**6 QUALITY*10**6

12	826692	995930
42	802642	929279
16	801053	918154
10	801053	918154
11	797963	892825

PLACEMENT IMPROVEMENT INITIATED

PLACEMENT IMPROVEMENT COMPLETED

PLACEMENT NUMBER 12

NET 10 STRAIGHT
NET 30 STRAIGHT

RATINGS

TOTAL	---	83.92 %
HORIZONTAL	---	4.36 %
VERTICAL	---	7.81 %
STRAIGHT NETS	---	66.67 %
QUALITY	---	0.99565

Figure 7. Folding Summary and Result Rating Output

included in the placement at this step, so statistics do not reflect pad placement.

After printing of result placement rating information, a pictorial representation of the cell layout is shown. This output for the example circuit is shown in Figure 8.

In this output, cell boundaries are shown as "#" and transistor boundaries as ":". Cell numbers are read vertically and occur to the left of the dashes. Numbers to the right of the dashes indicate nets which are incident to the cell. Transistors completely surrounded by #'s are transistors which are not used for cell placement.

Following placement depiction, the (row, column) positions assigned to circuit pads are shown. The position of each cell, pad, and group of unused transistors (A group of XXX unused transistors is denoted by 999XXX) is then shown in actual STAR grid coordinates. Finally, the set of barriers constructed to prevent router usage of unused pad positions is shown. This section of the output is shown in Figure 9.

PAD 102 PLACED AT 0.0 , 18.0
 PAD 101 PLACED AT 0.0 , 8.0

PLACEMENT

25	19	25	6	43	4	61	11	79
-41	7	25	14	43	3	61	12	79
41	8	25	13	43	2	61	5	79
-57	99	25	999003	67	1	76	999001	94
57	999012	25	17	61	9	79		
-73	999012	25	16	61	10	79		
73	999018	25	15	79				
-89	20	25	999004	67	18	79		
-25	101	39						
-25	102	69						

BARRIER CONSTRUCTED ON LEVEL 6 FROM 24 , 24 TO 38 , 24
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 39 , 90 TO 53 , 90
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 69 , 90 TO 83 , 90
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 84 , 90 TO 98 , 90
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 22 , 26 TO 22 , 40
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 22 , 42 TO 22 , 56
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 22 , 58 TO 22 , 72
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 22 , 74 TO 22 , 88
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 101 , 26 TO 101 , 40
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 101 , 42 TO 101 , 56
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 101 , 58 TO 101 , 72
 BARRIER CONSTRUCTED ON LEVEL 6 FROM 101 , 74 TO 101 , 88

OUTPUT FILE CONSTRUCTED

NORMAL CAPSTAR TERMINATION

Figure 9. Pad Placement, Grid Coordinate Translation,
 and Barrier Construction Output

Output File

The CAPSTAR output file is written on FORTRAN channel 19. This file contains the circuit cell type and net lists, the grid coordinate format of the placement, the locations of all constructed barriers, and any passed data from the input file. The format of this file for the example application is shown in Figure 10.

Execution of CAPSTAR on The XDS SIGMA/5

To run CAPSTAR on the SIGMA/5, the input data file should be constructed and a number of channel assignments made. A summary of channel definitions necessary is shown in Table 1.

Normally, the necessary assignments may be made by executing the file XEQCAPASGN which makes the device and file assignments shown in parentheses in Table 1.

After input file construction and channel assignment, the first portion of CAPSTAR can be run by

!LMBIGCAPA4.

The second part can then be run by

!LMBIGCAPB4.

TITLE EXAMPLE

STAR SIZE 8 24

GATES TO PATTERNS

1 1640	2 1640	3 1640	4 1640	5 1640	6 1640
7 1640	8 1640	9 1640	10 1640	11 1640	12 1640
13 1640	14 1640	15 1640	16 1640	17 1640	18 1640
19 1640	20 1820	99 1820	101 9200	102 9210	

PLACEMENT

25	19	25	6	43	4	61	11	79
-41	7	25	14	43	3	61	12	79
41	8	25	13	43	2	61	5	79
-57	99	25	999003	67	1	76	999001	94
57	999012	25	17	61	9	79		
-73	999012	25	16	61	10	79		
73	999018	25	15	79				
-89	20	25	999004	67	18	79		
-25	101	39						
-25	102	69						

NETS

10	1	4	2	4	3	4	4	4		
20	1	5	2	5	3	5	4	5	5	5
20	11	5	12	5	13	5	14	5		
20	15	5	16	5	17	5	18	5	19	5
20	20	5								
30	2	1	3	1	99	1	101	1		
40	4	1	102	1						

WIRES

6	24	24	38	24	BARR
6	39	90	53	90	BARR
6	69	90	83	90	BARR
6	84	90	98	90	BARR
6	22	26	22	40	BARR
6	22	42	22	56	BARR
6	22	58	22	72	BARR
6	22	74	22	88	BARR
6	101	26	101	40	BARR
6	101	42	101	56	BARR
6	101	58	101	72	BARR
6	101	74	101	88	BARR

Figure 10. CAPSTAR Output File

TABLE 1
CAPSTAR Channel Assignments

FORTTRAN Channel	Assigned
6	Narrative output device (LP)
12	Temporary File 0 (IEFILE)
13	STAR Pad Location File (STARPADLOC)
14	STAR Cell Width Library (STARWIDLIB)
15	Input Data File (INBUF)
16	Temporary File 1 (CAPTMP1)
17	Temporary File 2 (CAPTMP2)
18	Data Passage File (PASSFILE)
19	Output File (PLACEOUT)